From NETL's Office of Research & Development

Research news

July 2015, Issue 10

FEATURE STORY:

Alloy Raises the Bar for High-Temperature Performance

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the ENERGY lab
NATIONAL ENERGY TECHNOLOGY LABORATORY

U.S. DEPARTMENT OF ENERGY

Research news
July 2015, Issue 10

Contents

Research News is a monthly publication from the National Energy Technology Laboratory's Office of Research and Development. We focus on the exciting, cutting-edge research done at NETL by our scientists and collaborators to support the DOE Fossil Energy mission.

Jimmy Thornton, Associate Deputy of Outreach & Administration

NETL's Educational Programs

NETL has a number of educational programs available to undergraduates, graduates, post-docs, and faculty.

The Oak Ridge Institute for Science and Education (ORISE) Program allows participants to explore research challenges and opportunities at NETL. Undergrads within one year of receiving B.S., graduates within 3 years of receiving M.S., post-docs within 5 years of receiving Ph.D., and faculty are eligible. U.S. citizens, permanent residents, and foreign nationals with F-1 or J-1 visas can submit applications.

The **Mickey Leland Energy Fellowship (MLEF)** is a 10-week summer program open to U.S. citizens, particularly women and minorities, studying Science, Technology, Engineering, and Mathematics. Through the MLEF program, NETL mentors have access to a pool of interns from undergraduate to doctorate level interested in performing energy-related research for the summer.

The **National Research Council (NRC) Research Associateship Program** offers opportunities to post-docs interested in working on a particular project with a NETL Office of Research and Development researcher. Opportunities are also available for the Methane Hydrates Research Fellowship. Eligibility requirements vary based on program.

The **Office of Science Graduate Student Research (SCGSR) Program** provides funding to U.S. citizen graduate awardees to conduct part of their thesis research at a host laboratory in collaboration with a DOE scientist. The award period for the research project ranges from 3 to 12 consecutive months.

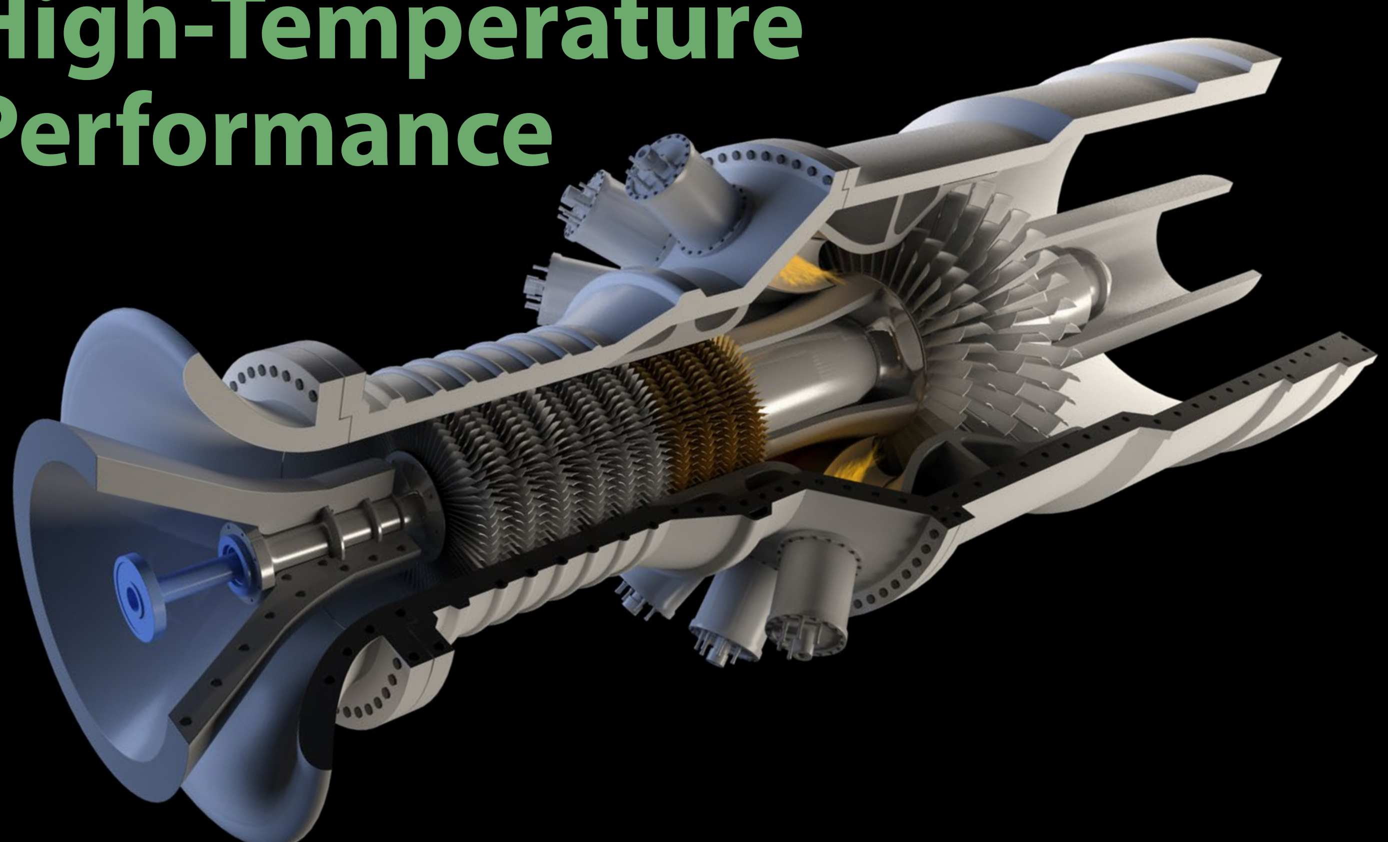
The Office of Science places interns at NETL for a twelve-week practicum experience through the **Computational Science Graduate Fellowship (CSGF)**. The CSGF is open to U.S. citizens working toward a Ph.D. in engineering and the physical, computer, mathematical or life sciences. Undergraduate seniors, applicants with a B.S. or B.A, and first-year graduate students (M.S. or Ph.D. students without an M.S. degree) are eligible.

For additional information, see http://www.netl.doe.gov/research/on-site-research/research-internships or contact Nancy Andres.

Cover image

Research Materials Engineer, Jeffrey Hawk, conducts material characterization experiments in NETL's Creep Laboratory.

ALLOY RAISES THE BAR FOR High-Temperature Performance



Advanced stainless steel alloys and fabrication processes enhance creep resistance in high-temperature environments, such as steam and gas turbines like the one depicted here.

NETL materials scientists have developed a new alloy that displays superior performance under high-temperature conditions. This new alloy, called CPJ-7, could find applications in advanced boilers and turbines, which will require materials with high-temperature creep strength (the ability to resist deformation over long times due to applied stress), corrosion resistance, and thermal fatigue resistance.

The operating efficiency of coal-fired power plants is directly related to combustion system temperature and pressure. Incorporating advanced ultrasupercritical (A-USC) steam conditions into new or existing power plants can increase efficiency, reducing coal use and carbon dioxide emissions. Under A-USC conditions, system components like boilers and turbines are exposed to extremely high temperatures and pressures, which contribute to aggressive oxidizing environments that either shorten component functional lifespan or require the use of thicker components or more costly alloys, resulting in increased cost. Conventional materials do not possess optimal characteristics for operation under A-USC conditions.

To make A-USC technology possible, researchers in NETL's Structural Materials Development Division have modified and developed many alloys for use in A-USC power plants. CPJ-7 is one example of an alloy that displays superior functionality under high-temperature and -pressure conditions.

According to Research Materials Engineer, **Jeffrey Hawk**, "During mechanical testing, CPJ-7 demonstrated creep life that was at least twice that of commercially available martensitic steels at equivalent stresses and temperatures. In addition, we have found the alloy to have more consistent and superior mechanical properties at temperatures up to 650 °C."

Martensitic grades of stainless steel, which contain higher levels of carbon and have different crystal structure, offer significant advantages over other types of stainless steel in terms of mechanical strength and thermal properties. The new material will provide improved performance at comparable cost to commonly used high-temperature steels. Performance of CPJ-7 has been demonstrated at a process scale that translates to industrial practice, making the new technology attractive for near-term commercialization.

Development of CPJ-7 was based on a multifaceted approach that builds upon existing alloy design fundamentals but also makes use of computational materials design strategies in the selection of steel chemistries suitable for high-temperature creep strength. Incorporation of a novel homogenization heat treatment process that allows for

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more uniform dispersion of the alloy's hard-to-disperse elements has led to the development of a material with improved oxidation resistance for high-temperature applications. Further, these alloys offer a potentially more cost-effective solution when compared to conventional nickel-based alloys for temperatures between 600°C and 650°C.

NETL's new alloy is expected to significantly extend the functional lifespan of selected components in advanced high-temperature power plants, including coal-fired boilers, steam and gas turbines, and piping. Outside of the energy arena, these alloys will have applications in aerospace, chemical manufacturing, metallurgical processing, and waste management. This new technology is available for licensing and/or further collaborative development through NETL's Technology Transfer program.

Contact: Jeffrey Hawk

Mechanical Testing Facilities

Scientists and engineers utilize the Mechanical Testing Laboratory to determine the mechanical behavior and performance of advanced materials under temperatures and pressures commonly associated with fossil energy systems. Understanding the high-temperature behavior of metals is critical to designing alloy formulations and processes for failure-resistant systems.

In this laboratory, technicians test novel materials with enhanced performance characteristics. The laboratory is equipped to test a material's ability to withstand cyclical mechanical loads for many cycles and evaluate resulting crack growth behavior of materials at temperatures up to 1000 °C. The lab can test a material's compressive and tensile strength—the resistance to breaking under compression or tension, respectively. Additionally, the lab has instrumentation for impact and hot-hardness evaluation.

The Creep Laboratory has instrumentation to evaluate creep strength, which is the ability of an alloy to withstand deformation under prolonged high temperature and mechanical stresses.

Creep testing is conducted at ambient pressure and at a range of operating temperatures. For example, creep-resistant martensitic steels are tested at temperatures up to 650 °C, while the nickel-based superalloys used in steam and gas turbines are tested at temperatures up to 800 °C. The duration of testing may also vary based on the alloy being evaluated. Typical tests last several thousand hours, but some alloys can be tested up to 25,000 hours.

Contact: Jeffrey Hawk

Jeffrey Hawk monitors materials characterization experiments at NETL's Creep Laboratory.

Patent Search Uncovers Promising Carbon Capture Innovations

Like detectives on a cold case, NETL researchers working on carbon capture and storage (CCS) dig deep into the obvious and the obscure to uncover clues that lead to innovation. A recent sleuthing exercise took the form of a revealing literature and patent search for potential CCS technologies—an effort that led to publication of a highly regarded and frequently cited research article that identified promising patents for small-scale carbon-capture technology innovations that could be considered options for larger scale coal-burning facilities.

Yuhua Duan of NETL's Molecular Sciences Division explained that the search for the best ways to capture and store CO_2 from large-scale industrial sources is an extremely high priority globally and nationally. As the fossil energy research arm of the Department of Energy, NETL pursues a holistic approach to harvest the best CCS ideas in the field for potential application to large-scale fossil fuel burning power plants.

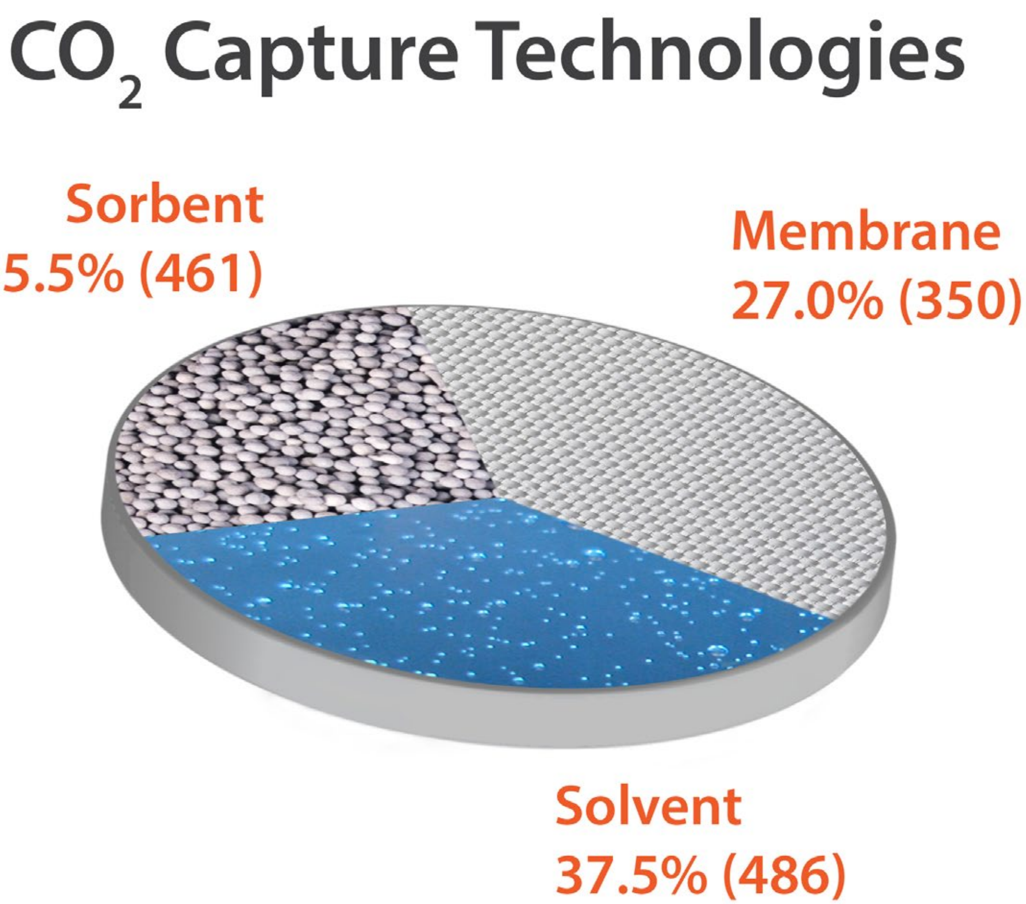
"A variety of methods have been studied and patented for the removal and separation of CO_2 from industrial waste and mine gases, the air, and from gases produced by animal metabolism," he said. "However, there are many technical challenges involved with large-scale economical implementation of CO_2 removal technologies."

He explained that almost none of the research focused on development of materials and processes for large-scale carbon capture considered the value of patented innovations designed for small-scale CO_2 removal and separation applications. A holistic approach that considers all innovations could yield positive results for addressing carbon capture approaches on a major scale.

"One key aspect of NETL's work is to conduct literature and patent reviews that provide full-range perspectives," he said. "These works are important contributions to the scientific literature and are of great interest to the overall research community because they provide a one-stop resource for innovation information. This is a way of bringing it all together for effective application."

The review was reported in "Advances in CO_2 Capture Technology: A Patent Review," a paper co-written with Bingyun Li of West Virginia University, NETL's **Bryan Morreale**, and former colleague David Luebke. The paper received recognition as an "Applied Energy Highly Cited Review Paper 2012-2013" from Elsevier—a leading provider of information to science, health, and technology professionals. Fewer than 2 percent of the papers appearing in Applied Energy are selected for the award.

Contact: Yuhua Duan

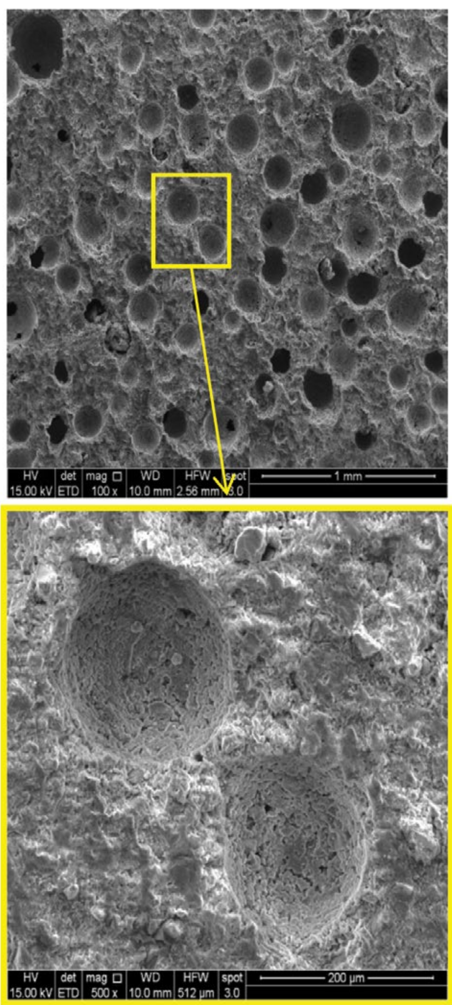


Numbers of solvent, sorbent, and membrane patents for carbon capture application through March 2012

Medical Imaging Equipment Provides an Inside Look at Oil and Gas Well Cements

Strength and stability of cements are critical in protecting the environment from leaks and spills wherever drills penetrate the earth in search of oil and gas. But what types of cement work best under the extreme conditions encountered in oil and gas wells, and what adjustments can be made to increase safety during oil and gas exploration and production on land and at sea? NETL's work on foamed cement is providing the answers.

NETL researchers polled industry to identify cement integrity issues after the 2010 Deepwater Horizon oil spill in the Gulf of Mexico, and the results led to an intensified effort at NETL to understand how variations in the structure of foamed cements impact wellbore effectiveness.



Scanning electron microscopy images of foamed cement with 20 percent entrained air (20 percent foam quality).

Foamed cement, created when gases like nitrogen are injected into cement slurry to form microscopic bubbles, is used in oil and gas wells because it can perform better than conventional cement under high temperatures and pressures, and provide a more reliable seal. But the stability of foamed cement depends on the distribution and size of the gas bubbles, which vary depending upon how the cement is pumped and placed in each wellbore. Unstable foams can result in unprotected sections.

Physical Scientist **Barbara Kutchko**, specializing in wellbore isolation, oil well cementing, and subsurface materials characterization, said NETL re-creates downhole conditions to see what happens when cement is generated and pumped into wells, and tests how it performs to determine the optimal foamed cement for each wellbore condition. Wells are increasingly drilled in extreme environments and at depths where cement is subject to harsh conditions, including elevated temperatures and pressures. Until NETL led an effort to study foamed cement, there was a lack of knowledge about how they performed in actual wellbore conditions.

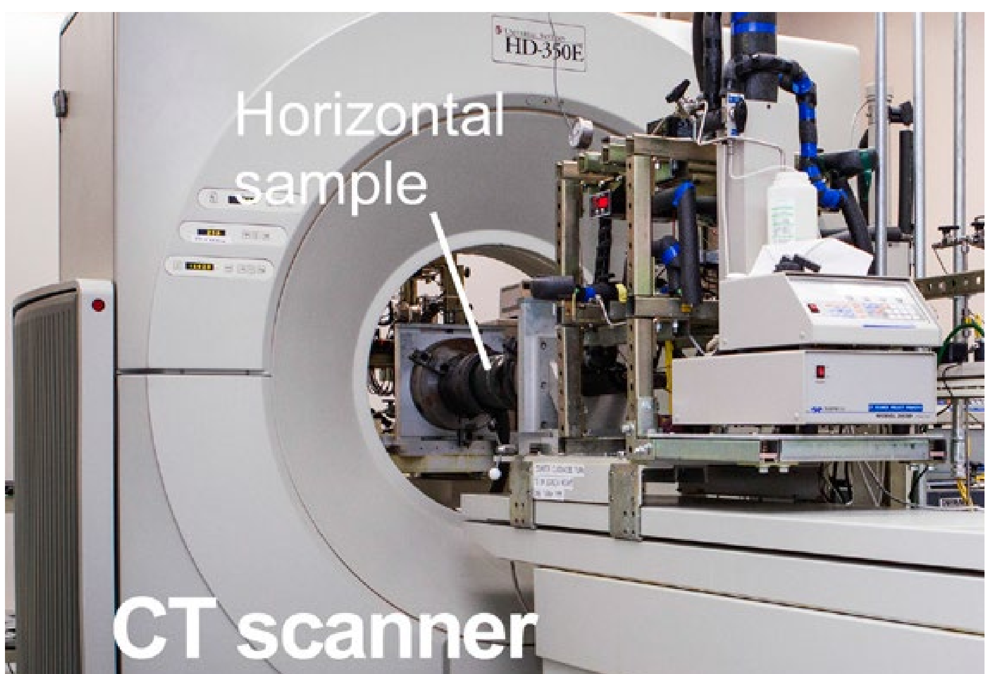
NETL, in a novel approach, adapted medical diagnostic equipment—CT scanners—to generate data and 3-D images of cement containing various amounts of air or nitrogen at atmospheric and wellbore pressures.

In addition, scanning electron microscopy (see black and white images) is used to measure bubble sizes in the foamed cement. These visualizations are correlated to physical properties such as permeability and strength.

The results include the first-ever high-resolution 3-D images of foamed cement and assessments of foamed cement structure, quality, and bubble size distribution—knowledge that can lead to better decisions for safer wellbores.

Today, drilling and cementing experts worldwide are using NETL research to understand how foamed cement production and placement affect the integrity of oil and gas wells. NETL shares that knowledge across the globe through interactions with the American Petroleum Institute and partnerships with academia.

Contact: Barbara Kutchko



A medical CT scanner adapted for foamed cement research at NETL.

PARTNERSHIPS WILL MANUFACTURE THE **FUTURE OF ENERGY**

Ron Adams (center), Interim VP for Research—Oregon State University, discusses strategies for advancing materials development.

What if it took ten to twenty years to get approval for a new metal alloy that – if used in a power plant – could make the plant operate more efficiently and produce fewer carbon emissions?

This isn't a hypothetical question, but a real-world barrier to greater sustainability of our energy production industry. It's also a question of interest to the US Department of Energy (DOE) – which has a goal of turning more of the energy inherent in coal into electricity – and to NETL – a DOE research laboratory with a long history of inventing new alloys for energy uses.

The current process for introducing new materials requires years of testing and data collection, and extensive review of the data by approval bodies. If successful, the new alloy will be 'qualified,' or approved for use in particular roles in a power plant, based on its ability to withstand high temperatures and pressures, corrosive materials, and routine fluctuations in these conditions. It's an effective process from the standpoint of screening out unsuitable materials, but the long times to approval can be a negative incentive for the commercial adoption of these new materials.

Recently, NETL and Oregon State University (OSU) hosted DOE leaders and materials experts from industry, the National Labs, and universities at an American Energy and Manufacturing Competitiveness (AEMC) Partnership dialogue. They discussed this and other barriers to deploying advanced materials to improve the Nation's power plants.

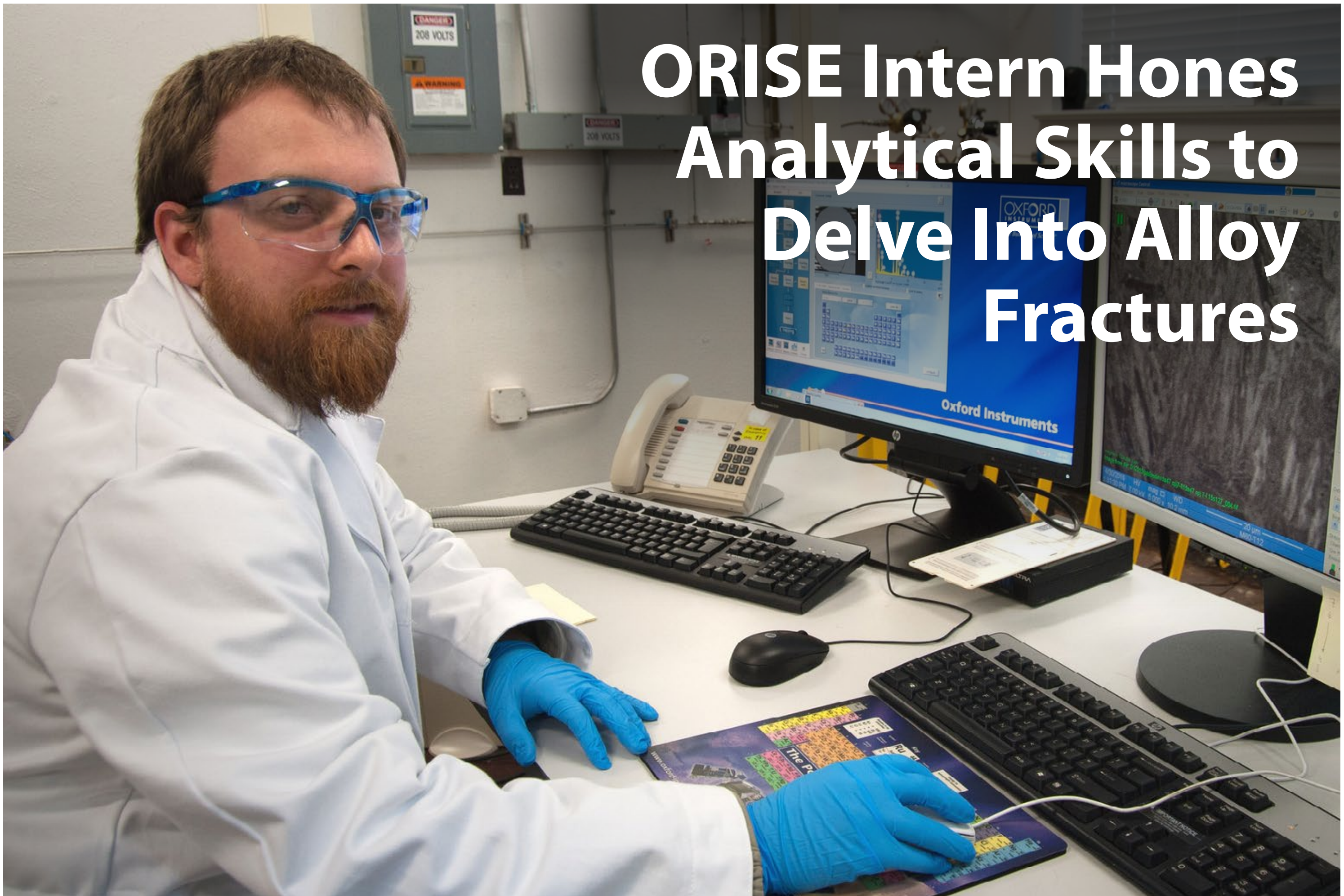
Accelerating computational speeds – important to analyzing enormous amounts of data – and revolutionary manufacturing technologies make this a "key moment" to address these problems, according to DOE's Julio Friedmann (Principal Deputy Assistant Secretary for Fossil Energy). NETL's Cynthia Powell, Director of the Office of Research & Development, tasked participants to help identify "what investment the federal sector can make to reduce risks" and enable development of materials that are not yet available. OSU's Ron Adams, Interim Vice-President for Research, spoke of bridging "transition points at the seams" between basic science in a laboratory and a product available in the marketplace.

In the past, collaborations between public and private entities have helped stitch those seams together, bringing materials from the lab to industry. Attendees agreed that it's important to bring together the right partners and have a well-defined problem. They also suggested pairing large businesses – who have more resources to conduct research – with small ones willing to take greater risks. DOE's National Labs, including NETL, can contribute the power of knowledge, making available scientific expertise and specialized facilities to invent, create, and test new materials, and by providing access to a plethora of data on materials performance.

Such approaches may help provide materials that reach the market faster, for a better future – fueled with clean energy. DOE and NETL want to help make that happen.

AEMC partnership dialogue sponsors. Front row: Chad Evans (Council on Competitiveness – CoC), Ed Ray (OSU President), Cindy Powell (NETL), Drew Steigerwald (CoC), Rueben Sarkar (Deputy Assistant Secretary, Transportation, Energy Efficiency and Renewable Energy, DOE); Back Row: Julio Friedmann (DOE); Mark Johnson (Director, Advanced Manufacturing, DOE), Bhima Sastri (Program Manager, Advanced Combustion & Fuel Cells, DOE).

ORISE Intern Hones Analytical Skills to Delve Into Alloy Fractures



Kyle Rozman examines data in his laboratory in Albany, Oregon.

NETL consistently enriches its research agenda by the Laboratory's participation in mentoring and internship programs like those administered by the Oak Ridge Institute for Science and Education (ORISE). NETL provides the world-renowned laboratories, equipment, and staff for an unparalleled educational experience, while the ORISE interns and research associates supplement NETL's expertise by supplying their enthusiasm and fresh perspectives. This synergistic relationship produces scientific breakthroughs greater than those that could be accomplished by the laboratory or the young scientists alone.

ORISE Research Associate **Kyle Rozman** is a great example of this successful symbiotic relationship. Rozman recently earned his Ph.D. from Oregon State University (OSU) based on his work in materials science at NETL, but his career at the laboratory began in 2009 when he was still a master's student. During this time, Rozman worked with **Margaret Ziomek-Moroz** investigating the failure of drill string alloys—advanced materials used in oil and gas drilling. The results of this work provided industry with important information to prolong the usable lifespan of their equipment.

After completion of his master's degree, Rozman began his Ph.D. studies with **Jeffrey Hawk** on nickel-based superalloys—materials that are engineered to withstand high heat and pressure found in turbines used for power generation. Rozman performed experiments that looked at fatigue crack growth rates in a specific alloy, Haynes 282. Rozman designed the experimental test methodology and then used electron microscopy to assess the deformation and fracture morphology (structural features). He showed that the propagation of the cracks occurred in a manner which would not prove detrimental to the alloy, even when significantly increasing the temperature. This investigation into superalloys provided data vital to determining if Haynes 282 would perform reliably as a rotor for the life of the steam turbine.

Rozman expressed gratitude for the support NETL, ORISE, and his mentors have offered him. "Everyone has been very friendly and willing to help with any questions or problems I may have," he said. In addition to the amazing researchers who have helped him along the way, including his current mentor, Lead Physical Scientist **Keith Collins**, the facilities and equipment available at NETL also made a lasting impression on Rozman.

"It was fascinating using the scanning electron microscope to look at microscopic striations on the fracture surfaces," Rozman said. "I learned valuable skills in analysis, and I look forward to a research career utilizing those analytical skills acquired though my time at NETL and OSU."

Contact: Jeffrey Hawk

One Million Hours!

What is one million hours worked? Using an average year and allowing for scheduled time off, an individual employee would have to work continuously for over 500 years to work one million hours! Individually, that goal is unattainable, but organizationally it is achievable – as NETL's Office of Research and Development (ORD) proved. This spring ORD passed a commonly recognized safety milestone by reaching ***one million hours worked without a lost or restricted work day injury***. As of June 30, the ORD workforce (including the Federal and site support contractor employees working on-site) has worked 1,149,121 hours - ***over 20 months*** - since the last lost time injury.

Lost time injuries are workplace injuries that are severe enough to require one or more days away from the job for medical treatment or recuperation; they also include injuries that prevent an employee from performing his/her normal duties over a normal work shift. Lost time injuries are recordable under OSHA criteria, so these injuries contribute to an organization's Total Recordable Injury Rate. They also contribute to the OSHA severity rate, a measure of the significance of injuries experienced by the organization. More importantly, lost time injuries mean someone we work with is unable to work because of a workplace injury or illness. Lost time injuries affect people – our co-workers and friends – and in that respect, they affect all of us in some fashion.

There is nothing magic about one million hours. It's just a large number used to normalize workplace injuries across companies and organizations of differing sizes. For most organizations, it requires a multi-year effort. For a hypothetical 100-person company, one million hours represents 5 years of continuous work. What is significant about one million hours is that reaching that milestone takes a conscious and concerted effort and collective commitment from all levels of the organization.

So, what happens now that one million hours worked is in our rearview mirror? ORD will move forward with a continued focus on safety in the workplace. While we recognize and celebrate one million hours without a lost time injury, our focus is not on the injuries that didn't happen, but on every task we undertake – individually and collectively. Reaching this milestone required a group effort; resetting to zero only takes one injury. By keeping focused on our tasks, using available tools and resources, and completing required training, by the end of next year, ORD could be recognizing two million hours of work without a lost time injury.

Contact: Mara Dean, Director, Crosscutting Research Support Division

NETL's In-House Research Program:
Turbine Thermal Management

Turbines can propel ships across the ocean and jets across the sky, and they produce the electricity that travels along the nation's power lines. In fact, the vast majority of power plants are outfitted with turbines consisting of stationary and rotating blades. When a gas or other fluid spins the rotating blades, a generator spins as well, producing electricity. Scientists and engineers at NETL are working together to improve the turbines that help keep our homes warm in winter, cool in summer, and well-lit year-round. Researchers in NETL's Turbine Thermal Management Program are seeking ways to make turbines perform more efficiently, operate longer, and emit less greenhouse gas. They use NETL's High-Pressure Combustion Research Facility, which houses a dynamic gas turbine and simulation validation test rigs, to advance three tasks:

- Provide theoretical, computational, and experimental analyses to reveal how a rotating detonation engine can improve the way turbines convert heat into mechanical energy. A rotating detonation engine has a circular combustion chamber, around which a carefully controlled sequence of detonations occurs to produce the thrust that powers a ship, air, or generator.
- Explore new methods for keeping turbine blades cool by testing cooling-hole designs to determine how well they reduce heat transfer and increase turbines' efficiency.
- Model components of supercritical carbon dioxide (sCO_2) systems, analyze their costs, and subject them to laboratory testing to advance turbine cycles that rely on sCO_2—instead of steam—to more efficiently spin the rotating blades in turbines.

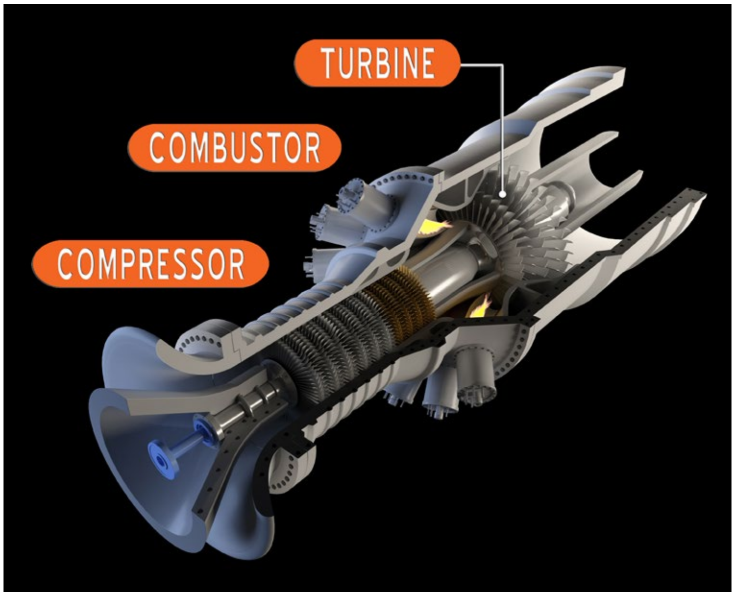
To learn more about the Turbine Thermal Management Program, contact Peter Strakey.

FUNDAMENTAL FACTS

Turbines and Electricity

Turbines are mechanical devices that serve as the backbone of electricity production. While the operations of most turbines are very similar, different turbines draw energy from different sources: water, steam, gas, or air.

For example, in gas turbines, incoming gas is compressed to high pressure as it moves through the compressor section. It is then heated to high temperature by the combustion of fuel in the combustor portion of the turbine. The high-temperature, high-pressure gas then passes through a series of rotor-mounted airfoils, causing them to spin at a speed consistent with the generator, which converts the kinetic energy of the moving gas into mechanical work. The turbine is connected to a generator, which uses an electromagnetic field to convert the mechanical energy into electricity. A steam turbine would operate similarly, using high-pressure steam to turn the turbine airfoils instead of combustion gases. Likewise, a hydroelectric turbine harnesses water as an energy source to turn the turbines.



The world's largest, most powerful, gas-fueled turbine is capable of running a 600 MW power plant that can supply 600,000 homes with electricity. Named Harriet, this gigantic (think school bus size) turbine is capable of producing air speeds equivalent to a category 5 hurricane. Air speed this strong could inflate the Goodyear blimp in 10 seconds. The incorporation of advanced alloys into the turbine blades coupled with integral cooling strategies and thermal barrier coatings allows Harriet to withstand temperatures of 2,900 °F (1,600 °C) resulting in an operating efficiency of over 61 percent—a major advancement in turbine technology.

Contact: Jeffrey Hawk

APPLAUSE

Patent Issued

Method for the Production of Fabricated Hollow Microspheroids, **Shan Wickramanayake** (AECOM), **David Luebke** (DOE/NETL); 9,050,579, issued June 9, 2015.

License Issued for NETL Intellectual Property

A license was issued on June 12, 2015, to LumiShield. This license was for a U.S. Provisional patent application number 61/995,405, titled "Ionic Solvent for the Aluminum Electroplating Process."

Kudos!

Pittsburgh Federal Executive Board, 2015 Excellence in Government Awards. And the winners are:
Doug Kauffman, Rookie of the Year (Gold)
Jamie Brown, Outstanding Supervisor (Silver)
Kelly Rose, Outstanding Professional Employee (Silver)
Kate Nielsen, Outstanding Professional Employee (Bronze)
Fuel Cell Sensor Team, Outstanding Team (Bronze)

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Council for Chemical Research "Rising Star" award goes to **Jordan Musser**. This award recognizes emerging talent in the United States in chemistry and chemical engineering. One of seven recipients of this award for 2015, Jordan was recognized for his outstanding development efforts to enhance the code capabilities of Multiphase Flow with Interface eXchange (MFIX).

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ORD wins "Best Poster" at the 2015 Joint Conference on Process Systems Engineering (PSE) and Computer Aided Process Engineering (CAPE). The poster was titled "Dynamic Response of Fuel Cell Gas Turbine Hybrid to Fuel Composition Changes using Hardware-based Simulations" and was presented by **Farida Nor Harun**, **Dave Tucker**, and **Tom Adams**.

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ORD: Science & Engineering To Power Our Future